QUANTITATIVE INVESTIGATIONS OF INTERFACES AND GRAIN BOUNDARIES BY PHASE CONTRAST ELECTRON MICROSCOPY WITH ULTRA HIGH RESOLUTION

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Recent progress in High Resolution Transmission Electron Microscopy makes it possible to investigate crystalline materials by phase contrast microscopy with a resolution close to the 80 pm information limit of a 300 kV field emission microscope[1-4)]. A reconstruction of the electron exit wave from a focal series of lattice images converts the recorded information into interpretable resolution[5,6)]. The present contribution illustrates some recent applications of this technique to interfaces.

Fig. 1 shows a reconstructed electron exit wave of a heterophase interface between GaN and sapphire. The experiment takes advantage of three factors: First, we resolved the GaN lattice in [1$\underline{1}$00] projection, which requires at least 0.15 nm resolution. The [1$\underline{1}$00] projection eliminates the stacking fault contrast that usually obscures lattice images in the commonly recorded [11$\underline{2}$0] projection. Thus, image interpretation is drastically simplified. Second, all atom columns at the interface and in the sapphire are resolvable with a smallest projected aluminum - oxygen spacing of 85 pm in the sapphire. Consequently, it is now possible to detect single columns of oxygen at a sub Angstrom spacing because of the excellent signal to noise ratio of the phase contrast image. Third, the reconstructed phase image is directly interpretable because a bright spot in the electron exit wave marks the position of atomic columns. The reconstruction procedure is applicable to any crystalline material. Figures 2 [7)] and 3 illustrate further examples of this technique to grain boundaries in metals and oxides.

Current efforts aim for a quantification of the information from the reconstructed exit waves. It has already been demonstrated that displacements of the atomic columns as small as 1 –3 pm can be extracted from lattice images or from the reconstructed electron exit wave [8,9)]. Furthermore, local thickness and chemical composition can in principle be accessed through the magnitude of the phase change[10)]. We tested the possibility of determining the number of atoms in [110] columns of gold, which is a suitable material because of its short extinction distance. From simulations (Figure 4a) one expects a maximum phase change of π in a column of only 9 Au atoms. Figure 4b depicts an experimental line trace across single columns of Au atoms in a reconstructed phase image from a wedge shaped sample. The largest recorded phase change in the experiment was normalized to π. It is seen that one would in fact count 8-9 Au atoms to reach the maximum. Therefore, it is feasible to detect the phase change of single gold atoms by quantitative analyses of the electron exit wave. [11)] In addition to demonstrating the current level of instrument performance, future needs and opportunities for quantitative HRTEM of interfaces will be discussed.

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